

VEVA DISCOVERY MISSION TO VENUS:
EXPLORATION OF VOLCANOES AND ATMOSPHERE

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ABSTRACT

VEVA (Venus Exploration of Volcanoes and Atmosphere) is a potential Discovery mission. It will provide a multidisciplinary investigation of the atmosphere and surface of Venus by returning the first-ever aerial photography of the surface and definitive, *in situ* determination of its atmospheric composition in the lower scale height. VEGA involves delivering an entry vehicle to Venus housing a payload consisting of an instrumented atmospheric sonde and a balloon-gondola system. After entry, the atmospheric sonde is released to fall to the surface, and the balloon package inflates, which arrests its descent at a 60-km float height. The balloon carries an instrumented gondola with battery power for 7 days as it circles Venus. The gondola carries four small imaging sondes for release and descent to the surface at different times during the 7-day mission. Data from the sondes are radioed to the gondola for relay to Earth.

SCIENCE OBJECTIVES

VEVA (Venus Exploration of Volcanoes and Atmosphere) is conceived as a potential Discovery mission involving a multidisciplinary scientific investigation of the atmosphere and surface of Venus.² VEGA will return the first-ever aerial photography of the surface of Venus and definitive, *in situ* determination of its atmospheric composition in the lower scale height. The objectives are to measure the vertical abundance of major reactive species from ~20 km to the surface, photograph the surface in a variety of volcanic settings with resolution as fine as 20 cm/pixel, collect near-infrared spectral reflectance data for the surface, assess the magnetic field strength, and measure the atmospheric temperature, net radiance, and aerosol abundance profiles. These goals will be accomplished by a balloon/gondola platform floating at 60 km altitude, an atmospheric chemistry sonde inserted directly upon arrival at Venus, and four small imaging sondes released to targeted sites during the balloon traverses. The expected results of this mission will improve our understanding of the complicated interaction between the dense atmosphere and the surface. Such information is crucial to formulating models for Venus' atmospheric and geologic evolution, which may be characterized by periodic catastrophic events.

Due to the unique coupling between the Venus surface and atmosphere, VEGA is by necessity a multidisciplinary project. Volcanic eruptions have shaped the surface, with over 80% of Venus being covered by volcanic flows forming vast plains or edifices.¹ Volcanic gases have shaped and continue to affect the atmosphere and likely provide the constituents that maintain the sulfuric acid cloud layer.⁶ The extensive volcanic plains may have been emplaced quite rap-

idly thus altering the atmospheric composition.¹³ To provide a baseline for understanding Venus' history and to search for traces of a possible global catastrophe, VEGA will address these specific science goals:

- *Characterize the chemistry of the lower atmosphere in order to understand surface-atmosphere interactions.*
- *Use isotopic gas abundances to provide a better model of atmospheric evolution on Venus.*
- *Analyze visual images and near-infrared spectra of the Venus surface to test models of plains emplacement, compare possible changes in volcanic style over time, provide a basis for enhanced interpretation of Magellan data, and assess the surface oxidation state.*
- *Characterize the temperature, pressure, net incident flux, and aerosol density profiles of the atmosphere.*
- *Determine the presence of a current or remnant crustal magnetic field.*

SCIENCE PAYLOAD

VEGA scientific goals are accomplished by three suites of instruments: a gas chromatograph-mass spectrometer (GCMS) system and a set of "Atmospheric Structure Equipment" (ASE) on the atmospheric composition sondes, camera systems and ASE on the imaging sondes, and a magnetometer and ASE on the gondola platform. Each ASE sensor assembly contains pressure and temperature sensors plus an integrated net flux radiometer and nephelometer instrument to assess aerosol particles and ambient light levels during descent. The miniature GCMS is used to make *in situ* atmospheric composition measurements of reactive species and noble gas isotopes over a range from 1 – 66 amu. Miniature cameras acquire aerial photography, including surface IR spectral reflectance measurements, at 4 sites with spatial resolution >100x better than current radar images. The miniature magnetometer will search for remnant crustal magnetism. The relationship between the instrument payload and the VEGA science objectives and measurement requirements is shown in Table 1 along with the instrument heritage.

MISSION OVERVIEW

VEGA launch is planned for November 2005 on a Delta 7925 rocket with a cruise period of about 170 days. The entry vehicle arrives in May 2006 on a Type 2 trajectory and descends directly into the atmosphere at a site near the eastern daylight terminator. The aiming point (near the summit of either Ozza or Maat Mons volcano) for the entry vehicle is either: (1) Ozza 4.8° N, 205° E, or (2) Maat 0.7° N, 200° E. The entry vehicle is separated from its carrier spacecraft about one hour before entry.

The entry vehicle's payload consists of an atmospheric sonde and a balloon-gondola system. An aerodynamic heat shield encloses the payload and provides initial g-load protection and support for the entry phase. After entry, the heat shield is jettisoned, the atmospheric sonde begins its fall to the surface, and the balloon inflates, which arrests its descent and provides lift to maintain a 60-km float height. The balloon carries an instrumented gondola with battery power for 7 days as it circles Venus. Each gondola carries four small imaging sondes for release at different times during the mission. Upon arrival, the terminator is at 220 E longitude, and the center of the planet as viewed from Earth is at 200 E (Figure 1). The balloon drifts west with the prevailing winds at about 75 m/s.¹¹

Science Objective (in priority order)	Measurement	Instrument	Heritage
Constrain chemical reactions between surface & atmosphere	Abundances of H ₂ O, COS, SO ₂ & other reactive species	Gas chromatograph Mass spectrometer	PV, Shuttle, ISS
Characterize albedo & morphology of volcanic constructs to constrain emplacement regimes & subsequent modification	> 60 images of 2 sites (1 with & 1 without high dielectric material)	Camera	STRV, Stardust
Compare old and young plains morphology to constrain emplacement mechanisms	> 60 images of 1 old and 1 young plains site	Camera	
Determine oxidation state of surface to constrain surface-atmosphere interaction	Vis-Near IR spectrum	Camera / IR filter	MISR, WFPC
Measure abundances of chemical constituents to constrain atmospheric evolution and planetary formation models	Noble gas isotopes	Mass spectrometer	
Determine the temperature, pressure, aerosol abundance, and net incident flux profile in the lower atmosphere to constrain lower atmosphere structure	Temperature, pressure, nephelometer, and net flux radiometer profiles through lower atmosphere	Venus Atmospheric Monitoring Package	MVACS, Mox
Determine field strength of Venusian crust to determine temperature history of planet	Triaxial magnetic field strength	Magnetometer	MO, MGS

Table 1. The measurements made by the VEVA payload relate directly to the science objectives. The instruments all have substantial flight heritage.

The atmospheric sonde free-falls to the surface in about 37 minutes. After drifting for ~2 hours, the balloon/gondola (with imaging sondes) is over its first target, and the first imaging sonde is dropped by a timer. The balloon continues the westward drift, dropping sondes at the other science targets (Figure 2). Each sonde free falls to ~5 km altitude above the local surface, where a gliding parachute opens to slow the descent and provide horizontal offsets between successive images.

Data from the GCMS sonde are radioed to the gondola for relay to Earth. Data from each imaging sonde are also radioed to the gondola. All sonde data will be downlinked during the ~2-day passage of the balloon across the Earth-visible hemisphere. The balloon/gondola continues to drift and take data on the far side of Venus, emerging in view of Earth at arrival+6 days when the science data taken out of view of Earth are downlinked. The mission ends at arrival+7 days.

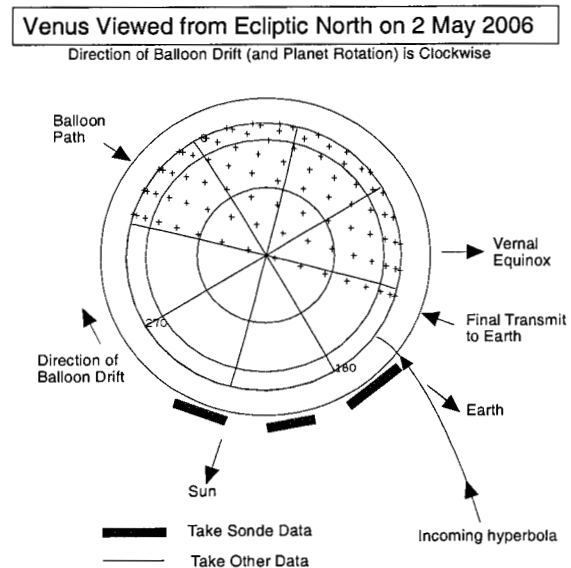


Figure 1. The geometry of the VEVA mission permits atmospheric entry with acceptable lighting and decelerations, while atmospheric winds carry the balloon/ gondolas around the planet in 7 days serving as a science platform and a radio relay for the drop sondes

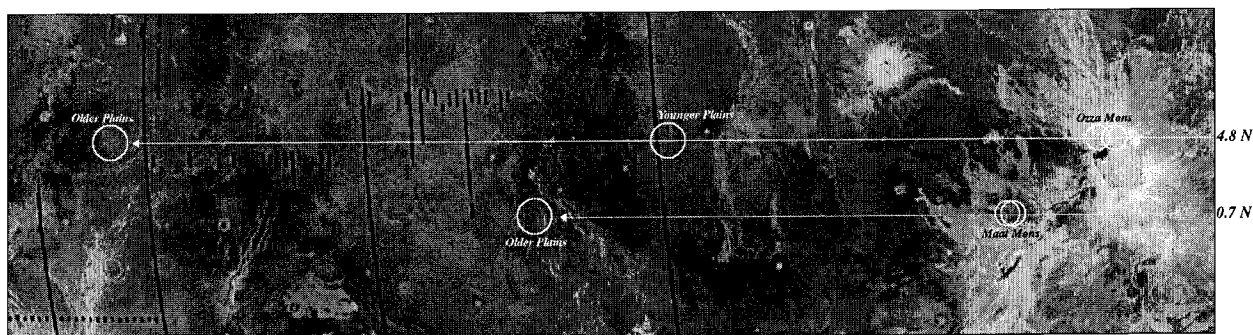


Figure 2. Potential VEVA ground tracks and drop sonde targets on Venus

OBSERVING STRATEGY

The GCMS sonde will begin operation at an altitude of about 20 km allowing 20 full GCMS measurements during the descent through the lower scale height (Figure 3). The VEVA target area for the four imaging sondes extends from Atla Regio westward to the volcanic plains of Rusalka Planitia (Fig. 2). Sites were selected to sample from four major Venus landforms: a volcanic upland region with highly radar-reflective properties, a potentially young volcanic highland with no enhanced radar reflectivity, an apparently old plains unit, and a stratigraphically younger plains unit.

Venus' atmosphere has an opaque cloud deck above ~47-km altitude. Our simulations show that by imaging below the cloud deck in a window in the CO_2 absorption at about $1\ \mu\text{m}$, interpretable images can be obtained even from 47 km altitude (images from this altitude will show primarily surface elevation differences due to the differing optical path lengths to the surface; lower areas will appear brighter).³ We also simulated the effects of near-isotropic lighting on aerial photographs and found that roughness-induced differences in apparent surface brightness (self-shadowing) provide good contrast between units even under these conditions.⁴

We will acquire an image taken soon after the sonde emerges below the cloud deck for direct correlation with Magellan images and to ensure context coverage (30-km scene width). For each site, successively higher-resolution images will be in the field of the higher-altitude synoptic scenes. To constrain the surface oxidation state and potential mineralogy, we include measurements of the IR reflectance spectrum from $0.5 - 1.0\ \mu\text{m}$.⁷ A total of about 60 images will be

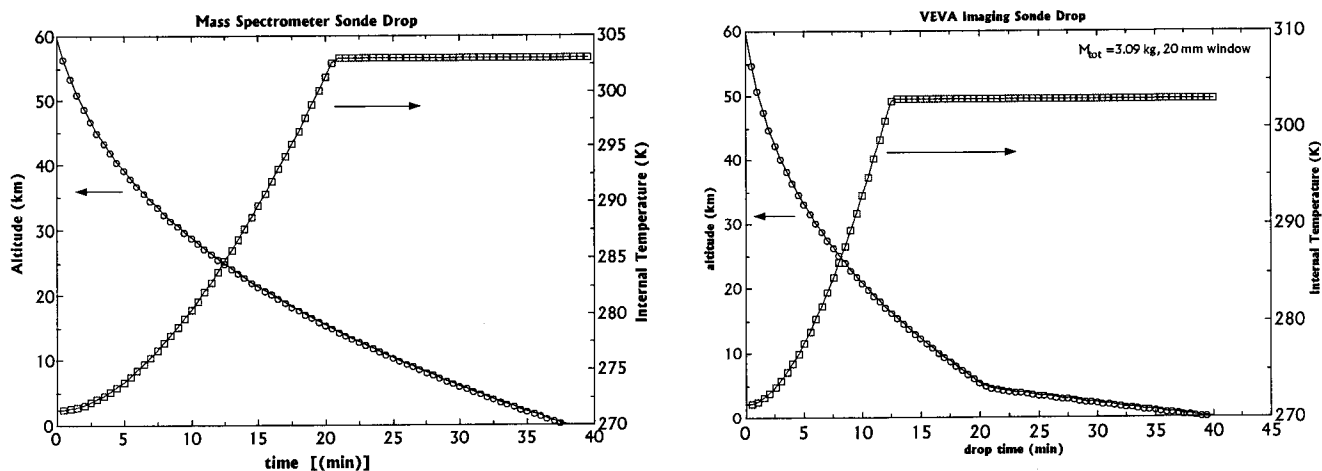


Figure 3. The descent profiles of the GCMS and imaging sondes

taken by each sonde, with the last photos having a scale of <20 cm/pixel, allowing the determination of the morphology of volcanic features and the presence of potential surficial deposits.

Continuous, direct ASE measurements of the solar flux and atmospheric scattering profiles from the drop sondes will constrain the vertical structure and physical properties of the clouds and the vertical distribution of solar energy. In addition, the balloon/gondola will carry the ASE and magnetometer for continuous operation during the balloon's circumnavigation of Venus.

SPACECRAFT

The VEVA flight system includes a carrier spacecraft, the entry aeroshell, the balloon/gondola, and the drop sondes. The carrier delivers the entry aeroshell and the science payload to the entry point at Venus (Figure 4). The entry aeroshell protects the payload during entry into and deceleration within the Venus atmosphere (Figure 5) and releases the payload at the proper altitude. The Balloon/Gondola system (BGS) includes a Deployment/Inflation system (DIS), used to place the gondola into its floating configuration. The science instruments are accommodated by the BGS and the two types of drop sondes, GCMS and imaging.

The carrier spacecraft is built by Lockheed Martin Astronautics (LMA). The structure and subsystems such as C&DH, telecom, propulsion, and AACS are based on the Mars Surveyor Program (MSP) lander cruise stage. The VEVA spacecraft delivers the entry aeroshells to a balloon deployment point with an error ellipse of semi-major axis <30 km.

The VEVA entry aeroshell provided by LMA use heritage from PV and Galileo. The entry aeroshell consists of a heatshield, a dome-shaped backshell, an event sequencer, and a small parachute system (Fig. 5).

The Balloon Gondola System (BGS) will be developed by JPL. BGS development benefits from the experience of the highly successful Russia/France/U.S. VENUS/VEGA balloon program¹² in 1985 and from JPL's Planetary Aerobot Program, which is developing technology and demonstrations for balloon missions.⁵ Upon separation from the aeroshell, the payload element is slowed by a 7-m parachute followed by balloon deployment and inflation to bring the BGS to

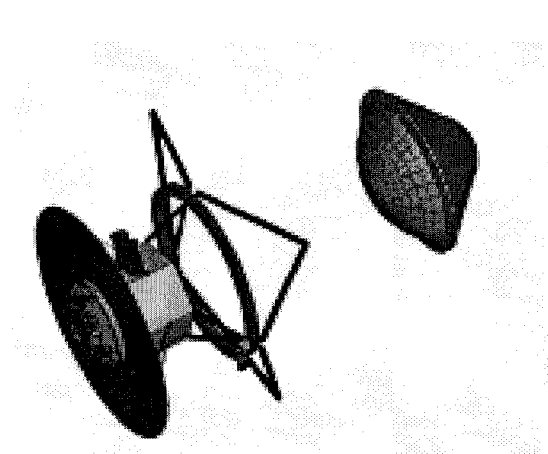


Figure 4. The VEVA carrier spacecraft releases the entry probe to its required target point

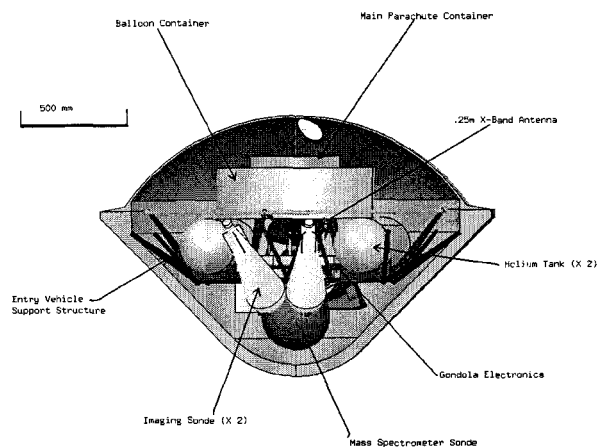


Figure 5. The gondola/sonde payload fits neatly within the entry vehicle, which supports and protects the payload through the atmospheric entry

its floating configuration (Fig. 6). After the mass spectrometer sonde is released, balloon inflation begins. In its floating configuration (Fig. 7), the BGS is supported by a 6.1-m diameter, bi-laminated mylar ($23\text{ }\mu\text{m} \times 23\text{ }\mu\text{m}$) superpressure helium balloon enclosed in a Teflon sheath to protect it from sulfuric acid. The sonde deployment ring supports all sondes during the float in the Venus atmosphere once the balloon is inflated (Fig. 7). The BGS avionics support entry/deployment sequencing and gondola operations. Power for the gondola is provided by a Li battery system. The BGS accommodates the ASE and magnetometer sensors using two gondola-mounted orthogonal spring-deployed booms.

The BGS will return a large volume of data from the sondes and its own instruments using a two-way X-band system for downlinking to the DSN at 10 kbps. The two degree-of-freedom X-band antenna on the gondola performs an azimuth-elevation scan pattern to acquire a DSN beacon signal, which it will autonomously track thereafter. The short range between the sondes and the gondola when the sondes are acquiring data (<200 km maximum) enables transmission over a UHF link to the gondola at 500 kbps for storage and relay to Earth.¹⁰ Table 2 summarizes the total data return capability.

Downlink Data Volume Capability/Day from Venus	1.75 Gbits
Onboard Data Storage Size per Gondola	2 Gbits
Days of Downlink Planned from Venus	2.7 days
Total Science Data Return from Venus	1.42 Gbits

Table 2. The downlink designs support the acquisition of the science data

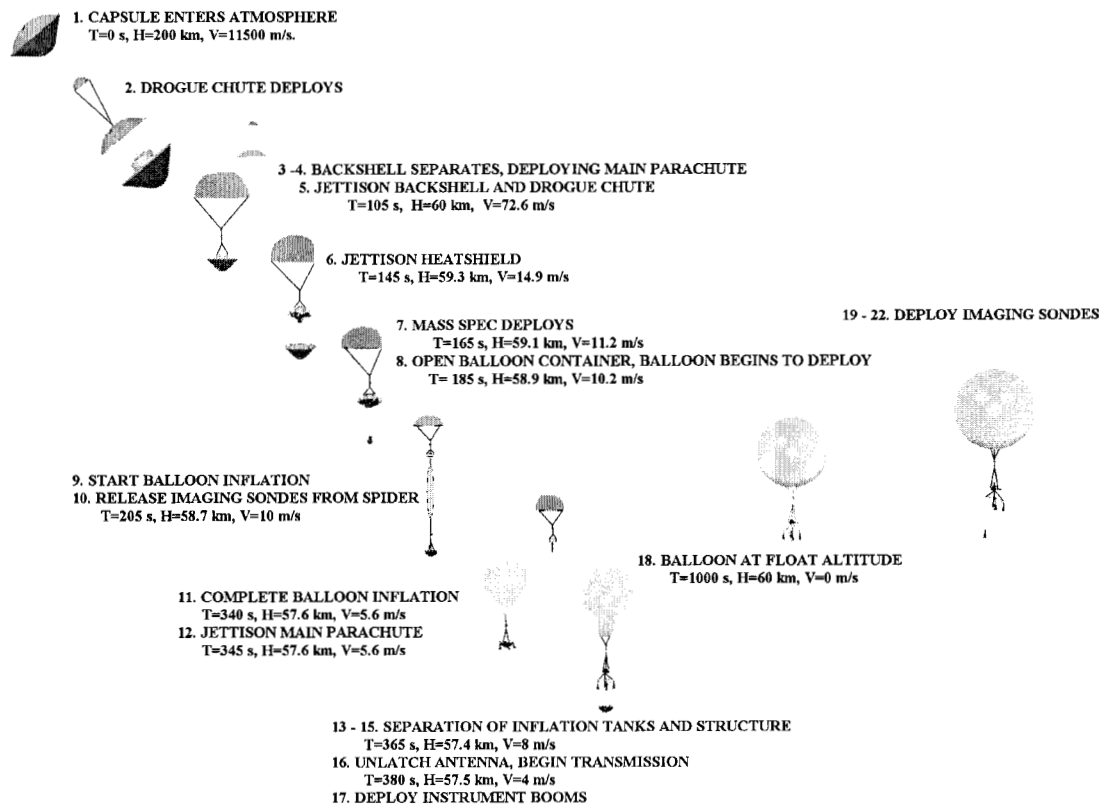


Figure 6. The sequence of events controlling entry, deployment, and inflation of the VEVA balloon is designed to achieve the desired floating configuration safely and reliably

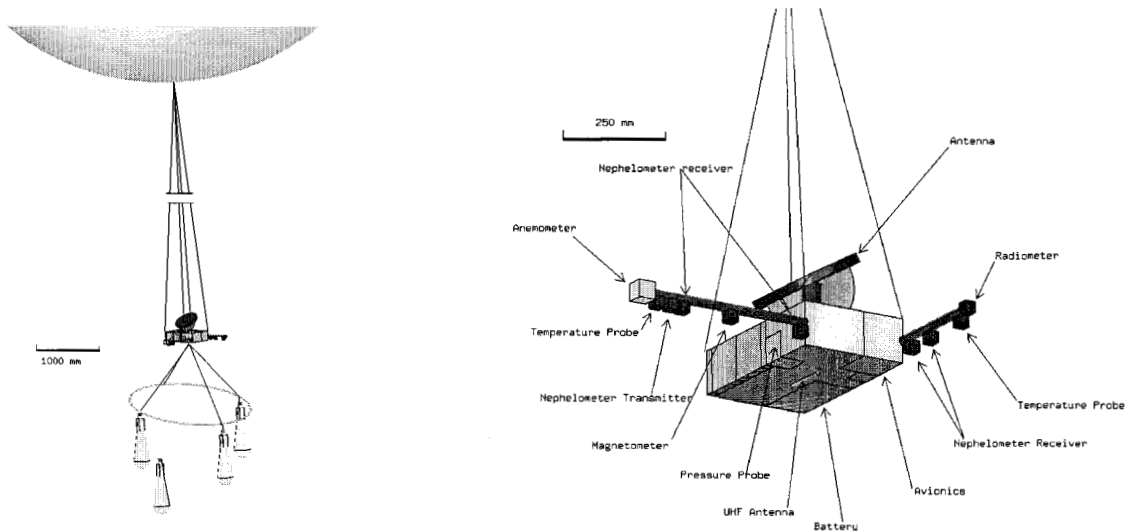


Figure 7. The sonde support ring (left) keeps the weight of the remaining sondes centered on the gondola as each sonde is sequentially dropped so as not to disturb its attitude. The gondola (right) provides the structural support for its science instruments and the communications antennae to enable successful collection and return of science data.

The drop sondes' mass spectrometer, camera, and ASE are accommodated in spherical pressure vessels 32 cm and 18.4 cm in diameter, respectively (Fig. 8).⁹ The sonde's pressure vessel and thermal stabilization components allow survival to the Venus surface conditions of 92 bars and 470°C.⁸ Instrument operating temperatures are maintained during descent using ~15-mm thickness of xenon-gas-filled porous fiberglass material as insulation for the vessel walls and a reservoir of thermal stabilizing $\text{LiNO}_3 \cdot 3\text{H}_2\text{O}$ phase-change material, which has a melting temperature of 30°C. An optical window in each imaging sonde allows the camera a Venus nadir view. Release of the imaging-sonde parachute is triggered by the controller at the appropriate altitude. Power is provided by Li batteries. Each sonde carries a UHF transmitter with a 1-W power amplifier.

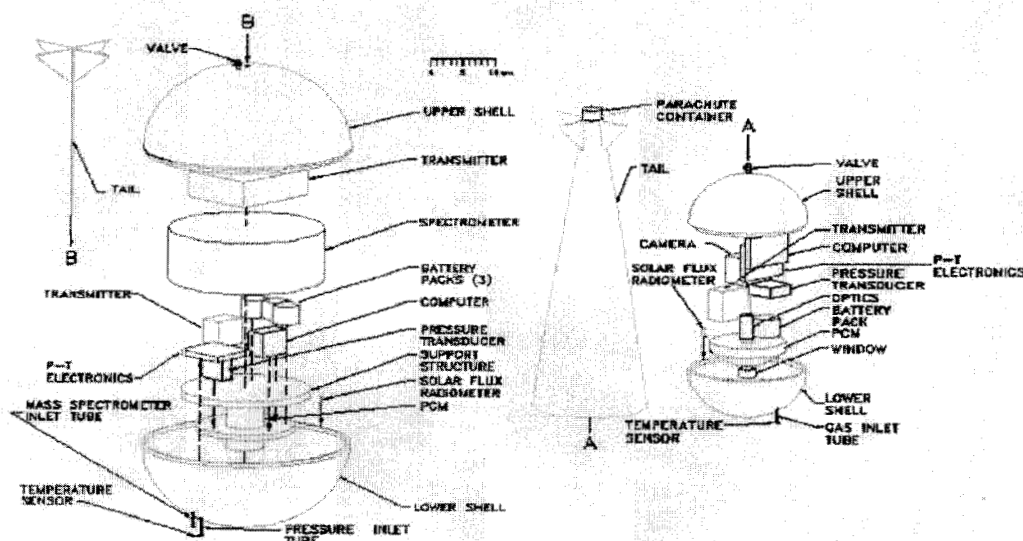


Figure 8. Miniaturization of instruments and supporting subsystems allow packaging in low-mass vessels for thermal and pressure protection during the descent to Venus' surface

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